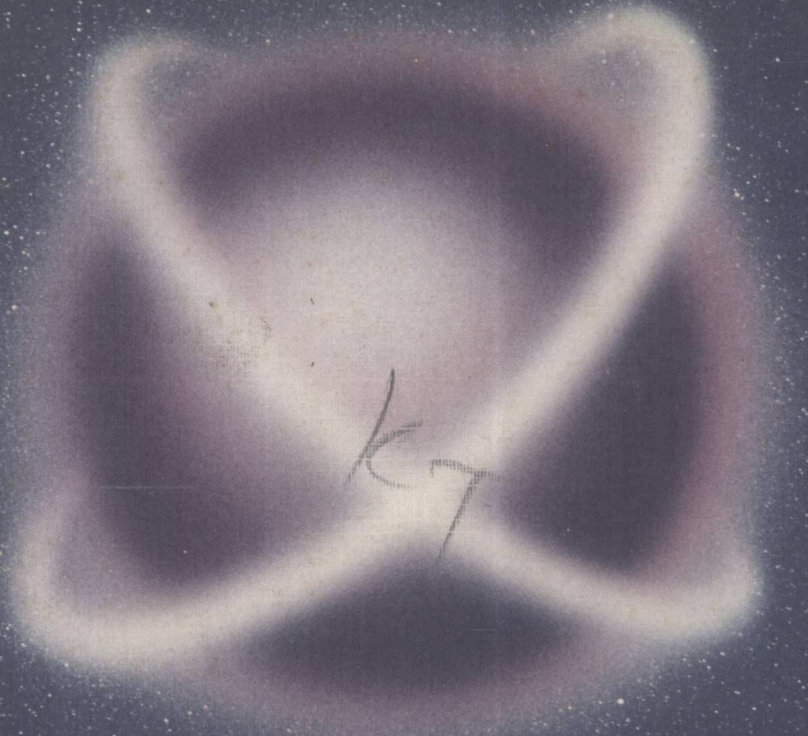

Calculations for A-level CHEMISTRY

E.N.RAMSDEN

CALCULATIONS FOR A-LEVEL CHEMISTRY

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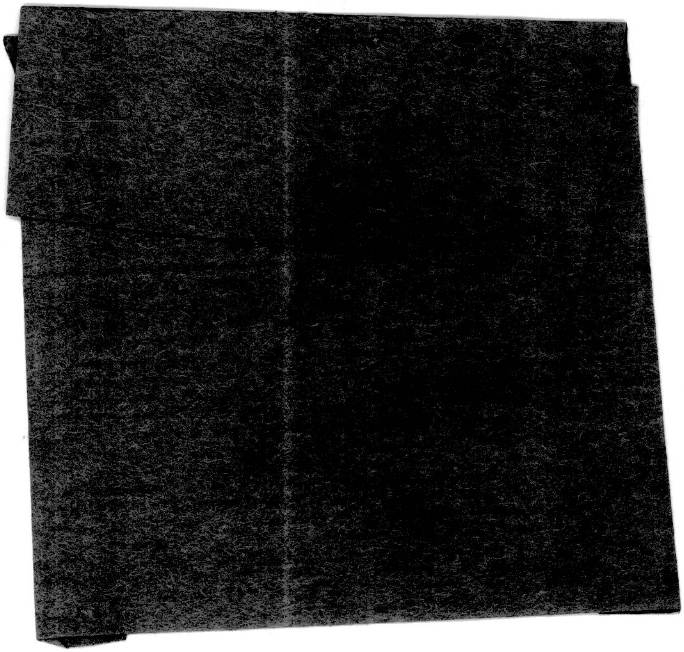

Foreword

It is a common complaint of university and college teachers of physical sciences that many of their incoming students are unable to carry out even simple calculations, although they may appear to have a satisfactory grasp of the underlying subject matter. Moreover, this is by no means a trivial complaint, since inability to solve numerical problems nearly always stems from a failure to understand fundamental principles, rather than from mathematical or computational difficulties. This situation is more likely to arise in chemistry than in physics, since in the latter subject it is much more difficult to avoid quantitative problems and at the same time produce some semblance of understanding.

In attempting to remedy this state of affairs teachers in schools often feel the lack of a single source of well-chosen calculations covering all branches of chemistry. This gap is admirably filled by Dr Ramsden's collection of problems. The brief mathematical introduction serves to remind the student of some general principles, and the remaining sections cover the whole range of chemistry. Each section contains a theoretical introduction, followed by worked examples and a large number of problems, some of them from past examination papers. Since answers are also given, the book will be equally useful in schools and in home study. It should make a real contribution towards improving the facility and understanding of students of chemistry in their last years at school and in the early part of their university or college courses.

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formerly Professor of Chemistry, University of Stirling

Preface

Many topics in Chemistry involve numerical problems. Textbooks are not long enough to include sufficient problems to give students the practice which they need in order to acquire a thorough mastery of calculations. This book aims to fill that need.

Chapter 1 is a quick revision of mathematical techniques, with special reference to the use of the calculator, and some hints on how to tackle chemical calculations. With each topic, a theoretical background is given, leading to worked examples and followed by a large number of problems and a selection of questions from past examination papers. The theoretical section is not intended as a full treatment, to replace a textbook, but is included to make it easier for the student to use the book for individual study as well as for class work. The inclusion of answers is also an aid to private study.

The material will take students up to GCE A- and S-level examinations. It will also serve the needs of students preparing for the Ordinary National Diploma. A few of the topics covered are not in the A-level syllabuses of all the Examination Boards, and it is expected that students will be sufficiently familiar with the syllabus they are following to omit material outside their course if they wish. S-level topics and the more difficult calculations are marked with an asterisk.

E N Ramsden
Hull 1982

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I thank the following examination boards for permission to print questions from recent A-level papers.

The Associated Examining Board

The Joint Matriculation Board

The Oxford and Cambridge Schools Examination Board

The Oxford Delegacy of Local Examinations

The Southern Universities Joint Board

The University of Cambridge Schools Local Examinations Syndicate

The University of London School Examinations Council

The Welsh Joint Education Committee

Many numerical values have been taken from the *Chemistry Data Book* by J G Stark and H G Wallace (published by John Murray). For help with definitions and physical constants, reference has been made to *Physico-chemical Quantities and Units* by M L McGlashan (published by The Royal Institute of Chemistry).

I have been fortunate in receiving excellent advice from Professor R R Baldwin, Mr G H Davies, Professor W C E Higginson, Dr K A Holbrook, Dr R B Moyes and Dr J R Shorter. I thank these chemists for the help they have given me. I am indebted to Mr J P D Taylor for checking the answers to the problems and for many valuable comments and corrections.

I thank Stanley Thornes (Publishers) for their collaboration and my family for their encouragement.

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Hull 1982

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List of Exercises

Questions from A-level papers are on the immediately preceding topic(s). Each question is appended with the name of the Examination Board and the year (80 = 1980 etc). p indicates a part question, S an S-level question and N a Nuffield syllabus. The most difficult (often S-level) questions are also denoted by an asterisk.

ABBREVIATIONS OF EXAMINATION BOARDS

AEB	Associated Examining Board
C	University of Cambridge Schools Local Examinations Syndicate
L	University of London Schools Examinations Council
JMB	Joint Matriculation Board
O	Oxford Delegacy of Local Examinations
O & C	Oxford and Cambridge Schools Examinations Board
SUJB	Southern Universities' Joint Board
WJEC	Welsh Joint Education Committee

1 Basic Mathematics

INTRODUCTION

Calculations are a part of your Chemistry course. To some students, they are a source of distress and dismay. To other students, they give the tremendous satisfaction of knowing that a problem has been solved, a correct answer obtained, and full marks gained for that question – a feat which it is not easy to achieve on other types of question!

Calculations are not just an extra activity: the time you spend on calculations will be richly rewarded. Your perception of Chemistry will become at the same time deeper and more precise. No one can come to an understanding of science without acquiring the sharp, logical approach that is needed for solving numerical problems.

To succeed in solving numerical problems you need two things. The first is an understanding of the Chemistry involved. The second is some facility in simple mathematics. Calculations are a perfectly straightforward matter. A numerical problem gives you some data and asks you to obtain some other numerical values. The connection between the data you are given and the information you are asked for is a chemical relationship. You will need to know your Chemistry to recognise what that relationship is.

This introduction is a reminder of some of the mathematics which you studied earlier in your school career. It is included for the sake of students who are not studying mathematics concurrently with their Chemistry course. A few problems are included to help you to brush up your mathematical skills before you go on to tackle the chemical problems.

WORKING WITH NUMBERS IN STANDARD FORM

You are accustomed to writing numbers in decimal notation, for example 123 677.54 and 0.001 678. In working with large numbers and small numbers, you will find it convenient to write them in a different way, known as *scientific notation* or *standard form*. This means writing a number as a product of two factors. In the first factor, the decimal point comes after the first digit. The second factor is a multiple of ten. For example, $2123 = 2.123 \times 10^3$ and $0.000\,167 = 1.67 \times 10^{-4}$. 10^3 means $10 \times 10 \times 10$, and 10^{-4} means $1/(10 \times 10 \times 10 \times 10)$. The number 3 or -4 is called the exponent, and the number 10 is the base. 10^3 is referred to as '10 to the power 3' or '10 to the third power'. You will have noticed that, if the exponent is increased by 1, the decimal point must be moved one place to the right.

$$2.5 \times 10^3 = 0.25 \times 10^4 = 25 \times 10^2 = 250 \times 10^1 = 2500 \times 10^0$$

Since $10^0 = 1$, this last factor is normally omitted.

When you multiply numbers in standard form, the exponents are added. The product of 2×10^4 and 6×10^{-2} is given by

$$(2 \times 10^4) \times (6 \times 10^{-2}) = (2 \times 6) \times (10^4 \times 10^{-2})$$
$$= 12 \times 10^2 = 1.2 \times 10^3$$

In division, the exponents are subtracted:

$$\frac{1.44 \times 10^6}{4.50 \times 10^{-2}} = \frac{1.44}{4.50} \times \frac{10^6}{10^{-2}} = 0.320 \times 10^8 = 3.20 \times 10^7$$

In addition and subtraction, it is convenient to express numbers using the same exponents. An example of addition is

$$(6.300 \times 10^2) + (4.00 \times 10^{-1}) = (6.300 \times 10^2) + (0.00400 \times 10^2)$$
$$= 6.304 \times 10^2$$

An example of subtraction is

$$(3.60 \times 10^{-3}) - (4.20 \times 10^{-4}) = (3.60 \times 10^{-3}) - (0.420 \times 10^{-3})$$
$$= 3.18 \times 10^{-3}$$

ESTIMATING YOUR ANSWER

One advantage of standard form is that very large and very small numbers can be entered on a calculator. Another advantage is that you can easily estimate the answer to a calculation to the correct order of magnitude (i.e. the correct power of 10).

For example,

$$\frac{2456 \times 0.0123 \times 0.004\,14}{5223 \times 60.7 \times 8.51}$$

Putting the numbers into standard form gives

$$\frac{2.456 \times 10^3 \times 1.23 \times 10^{-2} \times 4.14 \times 10^{-3}}{5.223 \times 10^3 \times 6.07 \times 10 \times 8.51}$$

This is approximately

$$\frac{2 \times 1 \times 4}{5 \times 6 \times 8} \times \frac{10^3 \times 10^{-2} \times 10^{-3}}{10^3 \times 10} = \frac{1}{30} \times 10^{-6} = 3 \times 10^{-8}$$

By putting the numbers into standard form, you can estimate the answer very quickly. A complete calculation gives the answer 4.64×10^{-8}. The rough estimate is sufficiently close to this to reassure you that you have not made any slips with exponents of ten.

LOGARITHMS

The logarithm (or 'log') of a number N is the power to which 10 must be raised to give the number.

If $N = 1$, then since $10^0 = 1$, $\lg N = 0$.

If $N = 100$, then since $10^2 = 100$, $\lg N = 2$.

If $N = 0.001$, then since $10^{-3} = 0.001$, $\lg N = -3$.

We say that the logarithm of 100 to the base 10 is 2 or $\lg 100 = 2$.

There is another widely used set of logarithms to the base e. They are called natural logarithms as e is a significant quantity in mathematics. It has the value 2.71828 . . . . Natural logarithms are written as $\ln N$. The relationship between the two systems is

$$\ln N = \ln 10 \times \lg N$$

Since $\ln 10 = 2.3026$, for most purposes it is sufficiently accurate to write

$$\ln N = 2.303 \lg N$$

Whenever scientific work gives an equation in which $\ln N$ appears, you can substitute 2.303 times the value of $\lg N$.

You will need to obtain the logs of numbers which are not integral powers of 10 (like 10^3 and 10^{-4}). There are two ways of doing this. One is to enter the number on your calculator and press the log key. The value of the log will appear in the display. This will happen whether you enter the number in standard form or another form. For example, $\lg 12\,345 = 4.0915$, whether you enter the number as 12 345 or as 1.2345×10^4. However, there is a limit to the number of digits your calculator will accept, and you need to enter very large and very small numbers in standard notation.

The other way of finding a log is to look it up in a set of log tables. Write the number in standard form, e.g. 2×10^3.

Then $\lg (2 \times 10^3) = \lg 2 + \lg 10^3 = 0.3010 + 3 = 3.3010$

You know that $\lg 10^3$ is 3, and you find out that $\lg 2 = 0.3010$ from the tables. 3 is called the *characteristic* and 0.3010 is called the *mantissa* of the logarithm. The log of 2×10^{-6} has a characteristic of -6 and a mantissa of 0.3010. It is written as $\bar{6}.3010$ or as -5.6990. Your calculator will display it as -5.6990.

Operations on logarithms are:

Multiplication. The logs of the numbers are added:

$$\lg(A \times B) = \lg A + \lg B$$

Division. The logs are subtracted:

$$\lg(P/Q) = \lg P - \lg Q$$

Powers. This is a special case of multiplication.

$$\lg A^2 = \lg A + \lg A = 2\lg A$$

$$\lg A^{-3} = -3\lg A$$

Roots. It is easy to show that $\lg\sqrt{B} = \frac{1}{2}\lg B$.

Since $$B = B^{1/2} \times B^{1/2}$$

$$\lg B = \lg B^{1/2} + \lg B^{1/2}$$

$$\lg B^{1/2} = \tfrac{1}{2}\lg B$$

Similarly, $$\lg\sqrt[3]{B} = \tfrac{1}{3}\lg B$$

ANTILOGARITHMS

To find a number from the logarithm of that number, you look up the mantissa in a table of antilogarithms. The number you obtain must be written with one digit in front of the decimal point. The mantissa 0.5949 gives the number 3.935. The characteristic of the logarithm becomes the exponent of the number. Thus the antilog of 3.5949 is 3.935×10^3.

Your calculator will give you the antilog of a number. You should consult the manual to find out the procedure for your own model of calculator.

Most calculators will give you reciprocals, squares and other powers, square roots and other roots directly. If you have a simpler form of calculator, you can obtain powers and roots by using logarithms.

ROUNDING OFF NUMBERS

Often your calculator will display an answer containing more digits than the numbers you fed into it. Suppose you are given the information that 18.6 cm^3 of sodium hydroxide solution exactly neutralise 25.0 cm^3 of a solution of hydrochloric acid of concentration 0.100 $mol\,dm^{-3}$. You want to find the concentration of sodium hydroxide solution, and you put the numbers $(25.0 \times 0.100)/18.6$ into your calculator and obtain a value of 0.134 408 6 $mol\,dm^{-3}$. The concentration of the solution is not known as accurately as this, however, because you cannot read the burette as accurately as this.

Since you read the burette to three figures, you quote your answer to three figures. In the number 0.134 408 6, the figures you are sure of are termed the *significant figures*. The significant figures are retained, and the insignificant figures are dropped. This operation is called *rounding off*. If the first number had been 0.134 708 6, it would have been rounded off to 0.135. If the first of the insignificant figures being dropped is 5 or greater, the last of the significant figures is rounded up to the next digit. If the first of the dropped figures is less than 5, the last significant figure is left unaltered.

Some calculations involve several stages. It is sound practice to give one more significant figure in your answer at each stage than the number of significant figures in the data. Then, in the final stage, the answer is rounded off.

If the calculation were $(25.0 \times 0.100)/26.2 = 0.095\,419\,84\ \text{mol dm}^{-3}$, would you still round off to 3 significant figures? This would make the answer $0.0954\ \text{mol dm}^{-3}$. Stated in this way, the answer is claiming an accuracy of 1 part in 954 – about 1 part in 1000. Since the hydrochloric acid concentration is known to about 1 part in 100, the answer cannot be stated to a higher degree of accuracy. You have to use the 3-significant-figure rule sensibly, and say that an error of ±1 in 95 is about as significant as an error of ±1 in 134. The answer should therefore be quoted as $0.095\ \text{mol dm}^{-3}$.

The number of significant figures is the number of figures which is accurately known. The number 123 has 3 significant figures. The number 1.23×10^4 has 3 significant figures, but 12 300 has 5 significant figures because the final zeros mean that each of these digits is known to be zero and not some other digit. The number 0.001 23 has 3 significant figures. The number 25.1 has 3 significant figures, and the number 25.10 has 4 significant figures as the final 0 states that the value of this number is known to an accuracy of 1 part in 2500.

In addition, the sum is known with the accuracy of the least reliable numbers in the sum. For example, the sum of

$$\begin{array}{rl} & 1.4167\ \text{g} \\ + & 100.5\ \text{g} \\ + & 7.12\ \text{g} \\ \hline & 109.0367\ \text{g} \\ \hline \end{array}$$

is 109.0367 g

Since 1 figure is known to only 1 place after the decimal point, the sum also is known to 1 place after decimal point and should be written as 109.0 g. The same guideline is used for subtraction.

In multiplication and division the product or quotient is rounded off to the same number of significant figures as the number with the fewest significant figures. For example, $12\,340 \times 2.7 \times 0.003\,65 = 121.6107$. The product is rounded off to 2 significant figures, 1.2×10^2.